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This effort explored the new phenomena in high speed semiconductor devices and structures intended for optoelectronics. While the details of progress made in each subject matter can be found in the publications, a list of which is provided, a few will be highlighted here.

A detailed investigation of the collector breakdown properties in GaAs/AlGaAs HBT's has revealed light emission at junctions edges for the first time. The spectral features when analyzed led to the determination of electron and hole threshold energies for ionization for the first time. Additional features observed may shed light into the processing mechanisms not otherwise conveniently accessible.

Other areas, e. g., modulation doped FET's, extremely low resistance nonalloyed ohmic contacts, HBT's on InP, quantum wells, optical properties of bulk AlGaAs and InGaAs were among many projects that were explored.

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III-V HETEROJUNCTION STRUCTURES AND HIGH SPEED DEVICES

U.S. Air Force AFOSR 86-0111

February 17,1989

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TABLE OF CONTENTS

I. SUMMARY

This effort explored the new phenomena in high speed semiconductor devices and structures intended for optoelectronics while the details of progress made in each subject matter can be found in the publications, a list of which is provided, a few will be highlighted here.

A detailed investigation of the collector breakdown properties in GaAs/AlGaAs HBT's has revealed light emission at junctions edges for the first time. The spectral features when analyzed led to the determination of electron and hole threshold energies for ionization for the first time. Additional features obsereved may shed light into the processing related mechanisms not otherwise conveniently accessible.

Other areas, e. g. , modulation doped FET's, extremely low resistance nonalloyed ohmic contacts, HBT's on InP, quantum wells, optical properties of bulk AlGaAs and InGaAs were among many projects that were explored.

II. PROGRESS MADE

Field-effect Transistors

A. MODFET Heterojunction Quantum Well

The modulation-doped field-effect transistor (MODFET) offers great promise for low-noise microwave amplification and high-speed switching. We have developed a new analytical model for eigenfunctions, eigen-energies, and related properties of the quasi-triangular quantum well in the MODFET. The model makes use of a new approximation for the potential energy function to simultaneously solve the Schrodinger equation and the Poisson equation. The potential energy function is general enough to represent the potential energy of quantum wells of MODFETs fabricated from all possible different semiconductors, having all possible doping conditions and mole fractions. In order to determine the applicability of the present model we have attempted to compare our results with those from five other models : (1) Classical model in which the subband structure is neglected, and the Maxwell-Boltzmann statistics is used to describe the electron distribution. (2) Classical model in which the subband structure is neglected, and the Fermi-Dirac statistics is used to describe the electron distribution. (3) Self-consistent field quantum mechanical model accounting for many body exchange and correlation effects in the framework of local density-function approximation. (4) Approximate quantum mechanical model using the triangular approximation for the quantum well. (5) Numerical method for exact calculations. It is noted that our results for Fermi energy level, sheet electron concentration, average electron distance from the heterointerface, and fractional subband occupancy agree almost quantitatively with the exact results from numerical calculations. These results appeared to be better than those from classical and semi-classical calculations, and from the quantum mechanical calculations with triangular potential approximation.

We have applied our model for the quantum well to calculate transconductance of AlGaAs/GaAs MODFETs. For this calculation use is made of a two-piece model for the saturation drift velocity. When compared with experimental results reported earlier by our laboratory, the calculated results show reasonably good agreements with them. Although not applied to various other systems, from the trend of the results obtained from the calculations, it is apparent that our model is general enough to be applicable to all systems of technological importance.

B. I-V Characteristics of JFETs

An analytical model has been developed to investigate the I-V characteristics of JFETs from various semiconductor materials, and with various doping conditions in the channel. The short-channel effect has also been studied. In order to study this short-channel effect, the field-dependence of the electron velocity in the channel of short-channel JFETs has been taken into consideration. A new approximation for the electron velocity has been used to develop analytical formulas for the drain saturation current, and intrinsic transconductance. This is given by

$$v = \left(\frac{N_d}{N_o}\right)^{\alpha} \frac{\mu(N_d)E}{1+\mu(N_o)E/v_s} \tag{1}$$

where N_d is the doping density in the channel, $\mu(N_d)$ is the doping dependent mobility of electrons, N_o and α are adjustable parameters, chosen to be $N_o = 10^{19}\ cm^{-3}$ and $\alpha = 0.333333$, E is the electric field, and v_s is the saturation velocity of electrons.

Results from eq. (1) have been compared with available experiments for GaAs and Ge. The comparison is encouraging.

In order to test the applicability of the present model we have performed calculations for JFETs from five different semiconductors : GaAs, Ge, Si, InP, and InGaAs. For these calculations we have considered the effects of both bandgap narrowing and Fermi-Dirac statistics. The bandgap narrowing has been modelled as

$$\Delta E_g = C_n N_d^{1/3} \tag{2}$$

where C_n is an empirical parameter; $C_n = 1.6 \times 10^{-8}$, 3.0×10^{-8}, 2.25×10^{-8}, 1.5×10^{-8}, and 1.6×10^{-8} eV/cm for GaAs, Si, InP, Ge, and $In_{0.53}Ga_{0.47}As$ respectively. Our results for drain saturation current and transconductance are found to be more sensitive to channel doping in the region $2 \times 10^{18} \leq N_d \leq 5 \times 10^{18}\ cm^{-3}$ than in the region $10^{17} \leq N_d \leq 2 \times 10^{18}\ cm^{-3}$. Both of these parameters are higher for shorter channel length than for longer channel length. The investigation suggests that, provided the leakage current is not high, a semiconductor alloy with composition suitable for the highest possible electron drift velocity should be most effective for high-speed JFETs. A submicron gate length would be the most effective for high-speed JFETs. A submicron gate length would, however, accompany short-channel effects. To circumvent these short-channel effects a channel doping higher than the 'Nulled Degeneracy Level' would be quite useful. The study indicates that the doping in the p-region gate of high-speed JFETs should not exceed a doping level of about 10^{20} cm^{-3}. This is because, in an attempt to satisfy charge neutrality condition such an exceedingly high gate would not allow drain electron velocity to saturate at a lower distance from the source end of the channel.

C. I-V Characteristics of MESFETs

High-speed low-cost monolithically integrated optoelectronic circuits using MESFETs (metal semiconductor field-effect transistors) are highly promising for low-wavelength optical communications. We have theoretically studied the I-V characteristics of both long-channel and short-channel MESFETs, the structure being grown by ion-implantation. For the modeling of this I-V characteristics of short-channel MESFETs we have taken the velocity saturation of electrons due to high electric field into account. Also, we have considered the effect of nonuniformity of band structure, and the effect of bandgap narrowing and Fermi-Dirac statistics for the heavily doped channel region. For the drift velocity of electrons use has been made of eq. (1). For the doping dependent mobility a new approximation has been made. It is given by

$$\mu(y) = \mu_L \left[\frac{A_1}{N_d^{\nu_1}} + \frac{A_2}{N_d^{\nu_2}} \right] \tag{3}$$

where A_1, A_2, ν_1, and ν_2 are empirical parameters given by $A_1 = 0.232676 \times 10^6\ cm^{-1}$, $A_2 = -3.0 \times 10^{15}$, cm^{-3}, $\nu_1 = 0.333333$, and $\nu_2 = 1.0$ respectively. $\mu_L = 10^4\ cm^2/V - s$ for GaAs and $1.4 \times 10^3\ cm^2/V - s$ for Si. To circumvent various difficulties arising from the integration of Gaussian profile for the drain region doping, we have made use of a fitting :

$$y^{-1} = \sum_{j=0}^{6} D_j exp(-\epsilon_j y^2) \tag{4}$$

where D_j and ϵ_j are appropriate fitting parameters.

In order to study the applicability of the present model we carried out calculations of drain saturation current I_{ds} and transconductance g_m for GaAs and Si. For the sake of calculation the drain saturation velocity for both GaAs and Si was chosen to be 10^7 cm/sec. Both I_{ds} and g_m are found to be very sensitive to the choice of channel doping as well as channel length. Both I_{ds} and g_m increase with increase in the channel doping and with decrease in the channel length. As higher value of the gate-source voltage V_{gs} causes higher modulation of electron conduction through the channel region, a higher value of V_{gs} leads to a higher drain saturation current and transconductance. The calculated variation of I_{ds} with V_{gs} agrees very well with available experiments.

Earlier device simulations by the relaxation time approximation method, and by the Monte Carlo method, which take the nonequilibrium electron transport in the channel into account, predicted that the electron velocity in submicrometer gate length MESFETs is higher than that in the micrometer gate-length MESFETs. Yamasaki and Hirayama measured the dependence of effective saturation velocity and threshold voltage on the gate length of GaAs MESFETs. We tried to study the implication of these results to the present method. It was noted that while we carried out calculations using increased saturation velocity and decreased threshold voltage for decreased gate length, our results agreed better with available experiments. Thus the present investigation strongly suggested that there occurs velocity overshoot in submicron gate length MESFETs.

D. Ion-implanted FET's

We have proposed a model for ion-implanted FETs that takes into account velocity-saturation effect. This model is expected to be more accurate than the previous models because it uses the exact doping profile instead of assuming an equivalent constant doping density. We have demonstrated that the results predicted by this model are in reasonable agreement with experimental data. Then we used this model to predict the dc characteristics of FET's with laterally graded doping profile, in particular, FET's with two different implants under the gate, the heavier doping being near the source. We studied the device performance as a function of the position of the implant-step and showed that it is in qualitative agreement with experimental data.

E. Backgating effect

We designed and fabricated a MODFET with a p-n junction back gate and demonstrated that the device current can be controlled by the normal front gate as well as the back gate quite efficiently. Also, we studied experimentally the variation of the transconductance as a function of the gate biases. This idea can be used in realizing novel structures that have been proposed in the past including the velocity modulation transistor. We also studied backgating effect in MODFET's that causes cross-talk in integrated circuits. To reduce this effect, we used p-n junction isolation and demonstrated that if the mesas etched deeper than the junction, excellent device isolation can be achieved.

F. GaAs-based FET's on InP

Metal-insulator-semiconductor-type AlGaAs/GaAs FET's have been successfully fabricated on InP substrates by incorporating an InGaAs/GaAs strained-layer superlattice in the buffer structure to reduce dislocation propagation into the active device region. A typical device shows an intrinsic transconductance of 180 mS/mm. It exhibits excellent pinch-off and large gate-to-source breakdown voltage. These devices will be useful for monolithic integration of GaAs-based electronic devices with InP-based optical devices for applications in low cost, high performance long wavelength optoelectronic integrated circuits (OEIC's)

Heterojunction Bipolar Transistors

A. InGaAs/InAlAs HBTs

We have undertaken a thorough investigation of InAlAs/InGaAs HBT's. This was to take advantage of the many distinct properties such as high electron mobility, low surface recombination velocity, and high valence band discontinuity afforded by this material system. In addition, these devices are compatible with 1.3-1.55 μm optical fiber communication systems. In some devices, we utilized an n^+-InAs emitter cap layer for nonalloyed contacts and obtained specific contact resistances of about 1.8 x 10^{-7} and 6.0 x 10^{-6} for emitter and base contacts, respectively. Since no high-temperature annealing is necessary, excellent contact surface morphology on thinner devices can easily be obtained. In devices with 50 x 50 μm^2 emitter area, common emitter current gain as high as 1500 were achieved at a collector current density of 2.7 x 10^3 A/cm^2. The p-n-p devices exhibited a common emitter current gain of up to 70 at a collector current density of 1.2 x 10^3 A/cm^2. To our knowledge, these values are the best reported to date.

We also succeeded in the first realization of InAlAs/InGaAs HBT's on GaAs substrates. Among the advantages of integrating InGaAs/InAlAs HBT's on GaAs are lower cost and less fragility of GaAs substrates, integration of InP-based optoelectronic systems with well developed GaAs technology, and elimination of ion diffusion from InP substrates during growth. Recently HBT structure with a compositionally graded emitter-base junction employing a linearly graded $In_{0.53}Ga_{0.47-x}Al_xAs$ between two ternary layers, and with a pseudo- quaternary InAlAs/InGaAs short period superlattice were investigated. Typical quaternary graded devices with an emitter dimension of 50 x 50 μm^2 exhibited a current gain as high as 1260 at a collector current density of 2.8 x 10^3 A/cm^2.

B. $Ge_{1-x}Si_x$ HBTs

Another area we investigated in heterojunction bipolar transistor was $Ge_{1-x}Si_x$ on Si substrate. Epitaxial growth of $Ge_{1-x}Si_x$ on Si has recently received much attention because of both fundamental interest in overlayer ordering as well as potential device application using tunable bandgap. Pursuing the realization of such a novel device, a study was undertaken to examine the potential performance of a n-Si emitter, p-Si_xGe_{1-x} base on a n-Si collector heterojunction bipolar transistor. Such a device combines the advantage of heterojunction with the advanced processing technology of Si. Using a compact transistor model, calculations of the high-speed capability of the transistor were performed revealing performance values superior to those for state-of-the-art Si bipolar transistors. Specifically, for an emitter area of 1 x 5 μm^2, an f_t of over 70 GHz and

f_{max} of over 30 GHz were computed at a collector current density of 1 x 10^5 A/cm^2 and V_{CB} of 5 V. As these simulations made use of fairly conservative dimension and device parameters, the simulated results are encouraging and suggest further investigation of this device.

C. GaAs/AlGaAs HBTs

We have continued our efforts to enhance the performance of GaAs/AlGaAs HBT's on Si substrates. Using optimized growth conditions, a series of HBT structure with varying parameters were grown on (100) Si substrate tilted 4° toward (110) by MBE. Devices exhibited current gains of about 45 at a collector current density of 2 x 10^3 A/cm^2, the highest current gain reported for GaAs/AlGaAs HBT's on Si to date. The diode characteristics exhibited remarkably high breakdown voltages of 10 and 15 V for emitter-base and base-collector junctions, respectively. The output characteristics of the n-p-n and p-n-p devices did not show any negative differential resistance (NDR), presumably due to the better thermal conductivity of Si substrates.

We have studied the avalanche breakdown behavior at the collector junction of the AlGaAs/ GaAs HBT. The dependence of collector-base breakdown voltage upon the collector doping concentration and thickness was reported, with the results showing expected functional behavior. Associated breakdown voltage calculations using simple punch-through considerations were found to be in close agreement with the maximum breakdown voltages – measured from devices displaying the most uniform junction breakdown.

Junction breakdown characteristics including both localized microplasma effects as well as uniform microplasma-free behavior were observed. At avalanche breakdown in the GaAs *p-n* junction, we reported the first known observation of light emission from the collector-base junction of a GaAs/AlGaAs HBT. Collector-emitter breakdown characteristics showing expected negative resistance breakdown were also studied. Associated current gain measurements were performed in connection with the analysis of the collector-emitter/collector-base breakdown voltages.

AlGaAs/GaAs HBT's have also been successfully fabricated on InP substrates. These devices, because of their superior high current handling capability, will be used for laser drivers for long wavelength optoelectronic monolithic integrated circuits on a single InP chip. Small-signal current gains of these HBT's were 30 on InP as compared to 150 for those on GaAs. The ideality factors of the emitter-base junctions were 1.3 and 1.2 for devices on InP and GaAs, respectively. Since the minority-carrier lifetime is quite sensitive to defects in the base region, these measurements demonstrate the high quality of GaAs on InP.

For the next research period, we plan to study and optimize HBT's performance to push their performance to the limit. As a one step further, the technology of HBT's will be applied to other novel devices such as resonant tunneling transistors. Most recently, a theoretical thermoelectro-feedback model has been developed for thermal designs of high power GaAs/AlGaAs HBT's. The power handling capability, thermal instability, junction temperature, and current distribution of HBT's with multiple emitter fingers will be investigated.

Non-alloyed ohmic contacts

We have developed extremely low resistance non-alloyed ohmic contacts to *n*- and *p*- type GaAs using superlattice contact layers consisting of small bandgap materials. The non-alloyed contacts on *n*- GaAs consist of InAs/InGaAs and InAs/GaAs superlattices and an InAs cap layer. Extremely low contact resistances of less than 8.5 x 10^{-8} Ω cm^2 have been reported. The non-alloyed contacts on *p*- GaAs consist of a GaAs/GaSb superlattice layer and a GaSb cap layer. A specific contact resistivity of 3.16x10^{-7} Ω cm^2 was obtained.

We incorporated the non-alloyed ohmic contact on *n*- GaAs described above on a conventional GaAs MESFET. Extremely low non-alloyed contact resistances of less than 5.0 x 10^{-8} Ω cm^{-2} have been achieved in this case, which is to our knowledge the lowest contact resistance obtained to date on GaAs. MESFETs with 1 μm gate lengths had transconductances of about 210 mS/mm.

We plan to take further steps in implementing these novel non-alloyed contacts in various other devices, especially those that InGaAs based, since the smaller bandgap of InGaAs coupled with the generally higher performance of these devices would make the availability of extremely low resistance non-alloyed contacts even more desirable.

We are conducting several studies relating to the growth of these superlattice contacts, primarily by transmission electron microscopy. We are also studying the effect of heat treatment on the resistance and uniformity of these non-alloyed contacts, as well as their sensitivity to the choice of contact metal.

Direct and resonant tunneling diodes

We have calculated the I-V characteristics of single barrier direct tunneling diode. The **k·p** model was used to calculate the transmission probability and two coupled Poisson's equations were used to calculate the band-bending. Quantitative agreement with experiment on an $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ diode was obtained. This method of calculation for the single barrier diode was directly extended to the double barrier resonant tunneling diode. And we are actively doing calculations on the latter.

We are currently doing research on three terminal resonant tunneling transistors. We will also simulate the I–V characteristics of this kind of devices using the same technique as with the two terminal devices.

Optical studies

A. Multiple Quantum Well Optical Modulators

Multiple quantum well (MQW) p-i-n modulators, based on the quantum-confined stark effect, have been demonstrated extensively for AlGaAs/GaAs and InGaAs/GaAs systems grown on GaAs substrates. As previously reported, we have demonstrated a InGaAs/GaAs strained layer MQW optical modulator based on the electro- absorption effect. A change of 27% in the transmission with 6 volt reverse bias voltage and at 0.971 μm wavelength was measured. As an extension, we investigated the reflection properties and demonstrated a p-i-n reflection modulator consisting of a 50 period strained layer $In_{0.15}Ga_{0.85}As/GaAs$ MQW and a 5 period AlAs/GaAs quarter wave stack dielectric mirror, grown on GaAs substrate. A relative change in the reflectivity of the modulator of 12% was observed with 4.5 V reverse bias voltage and at 0.996 μm wavelength. The reflection modulators are of interest for bidirectional communication systems, in parallel arrays of optical switching and processing devices, and for optical interconnects. With the progress of the GaAs on Si techinique, we have also investigated the optical properties of AlGaAs/GaAs MQW grown on Si substrates for the potential applications in optical -integration. Using photocurrent measurement, we observed the large excitonic absorption at room temperature for that material system. For the first time we demonstrated an optical reflection modulator and observed a 7.7% change in the reflectivity at wavelength of 0.86 μm for the device with 6 V reverse bias voltage across the AlGaAs/GaAs MQW p-i-n structure, grown on Si substrate.

B. Characterization of III-V materials grown by MBE

GaAsSb/GaAs strained layer MQW have been grown and characterized by photoreflectance (PR), photoluminescence (PL), and transmission measurements. For the first time we observed the PR features corresponding to the various subband transitions in GaAsSb/GaAs MQW at room temperature, indicating the greatly improved material quality. By the comparison between the theoretical calculated transition energies and the experimental observed ones, we determined the band offset for the $GaAs_{0.9}Sb_{0.1}$/GaAs interface of Q$\sim$1.7 for heavy holes, establishing a type II structure with electrons in GaAs layers and heavy and light holes in $GaAs_{0.9}Sb_{0.1}$ layer, respectively.

In our on-going research of InGaAs/GaAs strained layer MQW, we extended our studies from the confined to unconfined states. Optical transitions with energies higher than that of GaAs band gap in InGaAs/GaAs MQW have been observed. The theoretical calculations based on transfer matrix method were used to located the positions of unconfined subband energies. Reasonable agreement between the calculation and the observation were obtained. We found that the intensity of the transition involving unconfined subbands decreases with increasing well width, but is weakly dependent of the mole fraction, x.

In collaboration with T. A. Tombrello of CALTECH, we investigated and characterized the most important alloy system, AlGaAs, through optical absorption, PR, PL, as well as nuclear resonant reaction analysis. By using the energy gap E_g derived from the PR and absorption spectra and the AlAs mole fraction x determined from nuclear resonant reaction analysis, we obtained $E_g \sim x$ relation as E_g=1.424+1.427x+0.041x^2 (eV). The above relation shows larger slope and smaller bowing factor than those accepted earlier, and consistent with the most recently results reported by other groups.

The study of GaAs grown on InP substrate is of interest due to its potential applications in opto-electronic devices. We characterized the GaAs film grown on InP substrate through low temperature PL, transmission, and reflection measurements. Several important PL peaks were identified which include the excitonic and impurity associated transitions. From the fact that the excitonic peaks were observed in PL spectra, and that the reasonably good device characteristics were obtained, we have demonstrated that high quality GaAs film can be grown on InP substrate in spite of 4% lattice mismatch between two materials.

III. REPRESENTATIVE PAPERS

Analytical Model for I-V Characteristics of Ion-Implanted MESFETs with Heavily Doped Channel

S. Noor Mohammad, Mahesh B. Patil, James J. Chen, J.-I. Chyi,

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Abstract

A theoretical model for the I-V characteristics of ion-implanted MESFETs has been developed. A new formula for effective drift saturation velocity for electrons, and a Gaussian approximation for the inverse of reduced distances in the channel have eased the process of formulation. Theoretical formulas for early saturation of drain current and transconductance obtained in the framework of Lehovec-Zuleeg procedure, are quite simple and accurate. When calculated results from the present model are compared with available experiments, an encouraging correspondence between the two is observed. When used to study the appropriateness of the velocity overshoot and the softening of pinch-off voltage, it suggests that both of these phenomena are real in short-channel MESFETs, and these need to be carefully accounted for in a realistic model. The model is equally applicable also to ion-implanted JFETs.

Reference #494

Heavy doping for improved short-channel operation of GaAs MESFET

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Abstract

A theoretical calculation is performed to investigate the I-V characteristics of GaAs MESFETs. The calculation is based on a simple model that takes into account the dependence of electron mobility on electric field and doping. It is shown that velocity overshoot may be treated by an effective velocity higher than the bulk value.

Reference #493

Analytical treatment of MODFET heterojunction quantum well in GaAs/AlGaAs system

S. NOOR MOHAMMAD, M. SELİM ÜNLÜ and HADIS MORKOÇ, FELLOW, IEEE

Abstract

A new theoretical model has been developed to characterize the energy levels, eigenfunctions, and related properties of two-dimensional electron gas (2-DEG) formed in the quasi-triangular quantum well of a modulation doped field-effect transistor (MODFET). Rather than using a triangular form of potential, which is valid only for low electron densities in the inversion layer, the present model makes use of a realistic form of potential for the quantum well. This potential is versatile enough to fit almost every quantum well that may result from varying doping, mole fractions, and other parameters of the semiconductors forming the heterojunction. Numerical results, for example, for Fermi energy, fractional subband occupancy, etc. of the quantum well, and the transconductance of the MODFET containing this quantum well, are in very good correspondence with the exact and/or experimental results for the similar quantities of $Al_xGa_{1-x}As/GaAs$ system.

The authors are with the University of Illinois at Urbana-Champaign, Coordinated Science Laboratory, 1101 West Springfield Ave., Urbana, IL 61801-3082.

Reference #501

Analytical Model for I-V Characteristics of JFETs with Heavily Doped Channel

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Abstract

A theoretical analysis of the I-V characteristics of junction field-effect transistors (JFETs), which are useful for electronic and optoelectronic integrations, has been carried out in some details. Attempts have been made to study the effects of various device parameters, including carrier degeneracy and heavy doping of the channel and shortening of gate length, on the I-V characteristics of JFETs. A new theoretical model for drift velocity v in semiconductors has been proposed for this purpose. A comparison of results from this model with those from the existing model of Trofimenkoff and with available experimental data for v attests to the accuracy of the proposed model. Unlike almost all other models, the simple functional form of the proposed model provides it with additional advantages for application to the analytical I-V study of FETs with both uniformly and nonuniformly doped channels. Use of this model in the framework of Lehovec-Zuleeg procedure for short-channel FETs appears to provide reasonably good results. Whereever experimental data are available, they agree well with those from the present model. The latter demonstrates that a very heavy doping in the p-type gate does not yield higher transconductance. A submicron gate and a heavy doping (higher than the nulled degeneracy level) in the channel are, on the other hand, necessary for higher drain saturation current and transconductance. A semiconductor alloy with the highest possible electron saturation velocity is the most suitable for high-speed JFETs.

Reference #495

Modeling of Ion-Implanted Field-Effect Transistors

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Abstract

Interest in ion-implanted Field-Effect Transistors (FET's) has led to a study of device parameters as a function of implant parameters. In this paper, ion-implanted FET's are analyzed by considering the effect of electric field as well as doping density on the electron mobility. An effective mobility is defined such that the total current remains unchanged. This definition enables the calculation of device parameters for different implant conditions, gate lengths and material parameters. This computation is more efficient than two- dimensional numerical analysis. It is more involved than that employing an effective uniform doping profile. However, it is expected to be more accurate and allows direct theoretical comparison between different implant conditions. Such comparative analysis shows that a doping profile with a peak closer to the gate leads to improved transconductance and increased saturation current. The effect of source and drain resistance is taken into account by an iterative method. The degradation of device parameters due to these parasitic resistances is made clear. The model developed is compared with experimental data and is shown to produce reasonable agreement. Finally, the limitations of the model are pointed out.

Reference #485

Modeling of Filed-Effect Transistors

with Laterally Graded Doping

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Abstract

Field-effect transistors with a laterally graded doping profile are analyzed. In particular, two different doping profiles are assumed under the gate with lower doping near the drain. The dependence of mobility on doping density is taken into account. The effect of velocity saturation is considered through a simple approximation. Source and drain series resistances are taken into account by solving a nonlinear system of equations. Device parameters are computed as a function of the position of implant-step from the source. The results are found to be in reasonable qualitative agreement with experimental data. Finally, the limitations on the validity of this model are discussed.

Reference #492

Back-gated Field-Effect in a Double Heterostructure Modulation Doped Field-Effect Transistor

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Abstract

An $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ double heterojunction field-effect transistor has been fabricated, the novel feature being a p-n junction back gate. A device with $2\mu m$ channel length has yielded a change in transconductance by a factor of 2 for a change in back gate voltage of 1V. The performance of this device shows that this approach could be used in realizing novel devices such as velocity modulation transistor. Also, the change in threshold voltage with back gate bias could be useful in implementing digital circuits.

Reference #457

Reduced Backgating Effect in Modulation Doped Field-Effect Transistors by p-n Junction Isolation

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Abstract

Reduced backgating in modulation doped field-effect transistors (MODFET's) is achieved by p-n junction isolation. Before growing buffer layer for transistors, an AlGaAs p-n junction is included for isolating devices. Backgating characteristics are measured as a function of mesa depth and a dramatic reduction in backgating is observed when the mesas reach beyond the p-n junction. The dc performance of the MODFET is found to be comparable to previous results without such a p-n junction. Following this approach, great reduction in cross-talk between devices could be obtained in digital circuits.

Reference #465

$Al_{0.3}Ga_{0.7}As/GaAs$ MIS-TYPE FIELD-EFFECT TRANSISTOR FABRICATED ON InP SUBSTRATE

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Abstract

An MIS-type $Al_{0.3}Ga_{0.7}As/GaAs$ field-effect transistor *with 1-μm-long by 145-μm-wide* gates and intrinsic transconductace of 180 mS/mm has been demonstrated on InP substrate. The dislocation propagation is minimized by incorporating a superlattice on InP and a 1.5μm undoped GaAs buffer layer is grown prior to the actual channel to ensure good quality of the 250 Å active layer. A channel mobility of 1920 cm^2/Vs and a carrier concentration of 1.28×10^{18} cm^{-3} have been measured at 300 K. The device exhibits excellent pinch-off and the gate-to-source reverse breakdown voltage is greater than 5 V. The low output conductance of 2.5 mS/mm indicated small parallel conduction in the undoped GaAs buffer layer. Also, very little hysterisis was found in the i-v characteristics implying few traps in the epilayer.

Reference #449

A High Performance InGaAs/InAlAs Double Heterojunction Bipolar Transistor with Non-alloyed n^+-InAs Cap Layer on InP(n) by Molecular Beam Epitaxy

C. K. Peng, T. Won, C. W. Litton, and H. Morkoç

ABSTRACT

We have demonstrated an InGaAs/InAlAs double heterojunction bipolar transistor (DHBT) on InP(n) grown by molecular beam epitaxy (MBE) with high dc performance. An n^+-InAs emitter cap layer was used for non-alloyed contacts in the structure and specific contact resistances of 1.8×10^{-7} and 6.0×10^{-6} $\Omega{*}cm^2$ were measured for the non-alloyed emitter and base contacts, respectively. Since no high temperature annealing is necessary, excellent contact surface morphology on thinner base devices can easily be obtained. In devices with 50×50 μm^2 emitter area, common-emitter current gains as high as 1,500 were achieved at a collector current density of 2.7×10^3 A/cm^2. To our knowledge this is the highest current gain ever obtained in In based structures grown by MBE.

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Reference #428

$In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ Double Heterojunction PnP Bipolar Transistors by Molecular Beam Epitaxy

by

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Abstract

PnP $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ double heterojunction bipolar transistors with a p^+-InAs emitter cap layer grown by molecular beam epitaxy have been realized and tested for the first time. A 15 Å-thick $In_{0.53}Ga_{0.47}As$/ InAs five period superlattice was incorporated between $In_{0.53}Ga_{0.47}As$ and InAs emitter cap layer to smooth out the valence band discontinuity. Specific contact resistances of 1×10^{-5} and 2×10^{-6} Ωcm^2 were measured for non-alloyed emitter and base contacts, respectively. The maximum common emitter current gain of 70 have been measured for 1500 Å-thick base transistors at a collector current density of 1.2×10^3 A/cm^2. The current gains of the typical devices with an emitter area of 50×50 μm^2 were around 50 with an ideality factor of 1.4.

Reference #436

An $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ heterojunction bipolar transistor on GaAs by molecular beam epitaxy

by

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Abstract

We report on the first $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ heterojunction bipolar transistors grown on a GaAs substrate. In order to suppress the propagation of threading dislocations to the surface, a ten period $AlAs/In_{0.52}Al_{0.48}As$ (20Å/20Å) strained layer superlattice were repeated twice with intervening undoped $In_{0.52}Al_{0.48}As$ layers. The typical common emitter current gain in 50 x 50 μm^2 emitter area devices was 50, with a maximum of 63, at a collector current density of 2×10^3 A/cm^2.

High Speed Performance of $InP/In_{0.53}Ga_{0.47}As/InP$

Double Heterojunction Bipolar Transistors

by

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Abstract

A theoretical comparison of $In_{0.53}Ga_{0.47}As/InP$ and $Al_{0.3}Ga_{0.7}As/GaAs$ heterojunction bipolar transistors has been undertaken in an effort to determine the relative merits of these material system. The analysis uses a compact transistor model and considers devices with self-aligned geometries including both extrinsic and intrinsic parameters. The high electron mobility in the $In_{0.53}Ga_{0.47}As$ base layer and high peak velocity of electrons in the collector depletion layer result in a current gain cutoff frequency in excess of 150 GHz for an $InP/In_{0.53}Ga_{0.47}As$ transistor with base thickness of 0.1 μm. Calculation revealed, however, that maximum oscillation frequency is strongly dependent on the contact resistance of the p-type base layer even for self-aligned base transistor. A maximum oscillation frequency of 138 GHz is theoretically predicted for an $InP/In_{0.53}Ga_{0.47}As$ transistor with base thickness of 0.06 μm, base doping of $1 \times 10^{20} cm^{-3}$, a p-type contact resistance of $1.0 \times 10^{-7}\ \Omega\ cm^2$, a current density of $5 \times 10^4\ A/cm^2$, and a V_{CB} of 5 volt.

Reference #420

Heterojunction Bipolar Transistors (HBTs) for Millimeter-wave and Optoelectronic Applications

by

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Abstract

This paper reviews the theory, governing parameters, and current status of heterojunction bipolar transistors fabricated using GaAs/AlGaAs and other III-V compounds. Because of many distinctive advantages over FETs such as higher current handling capability, elimination of stringent submicron lithography for high speed, and low 1/f noise, HBTs are of promise for future millimeter-wave and microwave integrated circuits. Fueled by the advancements of epitaxial growth and fabrication technologies, the devices with an f_{max} of 175 GHz and an f_t of 105 GHz have already been obtained. Epitaxial growth has reached a level where a whole host of new materials can be exploited for enhanced performance.

Reference #469

High-speed Performance of Si/$Si_{1-x}Ge_x$ Heterojunction Bipolar Transistors

by

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Abstract

A theoretical investigation of Si/$Si_{1-x}Ge_x$ heterojunction bipolar transistors has been undertaken in an attempt to determine their speed potential. The analysis is based on a compact transistor model and devices with self-aligned geometry, including both extrinsic and intrinsic parameters, are considered. For an emitter area of 1 x 5 μm^2, an f_t of over 70 GHz and f_{max} of over 30 GHz were computed at a collector current density of 1 x 10^5 A/cm^2 and V_{CB} of 5V.

Reference #470

A High Gain GaAs/AlGaAs NpN Heterojunction Bipolar Transistor on (100) Si Grown by Molecular Beam Epitaxy

by

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Abstract

High gain GaAs/AlGaAs NpN heterojunction bipolar transistors on Si substrates grown by molecular beam epitaxy have been fabricated and tested. In this structure, a n^+-InAs emitter cap layer was grown in order to achieve a better ohmic contact. Typical devices with an emitter dimension of 50 x 50 μm^2 exhibited a current gain as high as 45 at a collector current density of 2 x 10^3 A/cm^2 with an ideality factor of 1.4. To our knowledge, this is the highest current gain reported for HBTs grown on Si substrates. Breakdown voltages as high as 10 and 15 V were observed for the emitter-base and collector-base junctions, respectively. The investigation on devices with varying emitter dimensions demonstrates that much higher current gains can be expected by reducing the surface recombination at the periphery of the emitter junction.

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GaAs/AlGaAs Heterojunction Pnp Bipolar Transistors

Grown on (100) Si by Molecular Beam Epitaxy

by

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Abstract

GaAs/AlGaAs Pnp heterojunction bipolar transistors (HBTs) were fabricated and tested on (100) Si substrates for the first time. A common emitter current gain of $\beta = 8$ was measured for the typical devices with an emitter area of 50 x 50 μm^2 at a collector current density of 1 x $10^4 cm^2$ with no output negative differential resistance up to 280 mA, highest current used. A very high base-collector breakdown voltage of 10 V was obtained. Comparing the similar structures grown on GaAs substrates, the measured characteristics clearly demonstrate that device grade hole injection can be obtained in GaAs on Si epitaxial layers despite the presence of dislocations.

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Reference #443

AlGaAs/GaAs Single Heterojunction Bipolar Transistors Grown on InP by Molecular Beam Epitaxy

by

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ABSTRACT

AlGaAs/GaAs single heterojunction bipolar transistors grown on InP substrates by molecular beam epitaxy have been fabricated and tested. An eight period 25 Å /25 Å $In_{0.53}Ga_{0.47}As/GaAs$ strained layer superlattice is incorporated in the buffer structure to reduce dislocation propagation to the active region. Small-signal common emitter current gains of about 20 and 30 at a collector current density of 2×10^3 A/cm^2 have been obtained for devices on InP as compared to about 60 and 150 for those on GaAs in structures with base thickness of 0.12 μm doped with Be to 1×10^{19} and 1×10^{18}cm^{-3}, respectively. Current densities as high as 1×10^4 A/cm^2 have been achieved in these devices with emitter area of 50 x 50- μm^2 without degradation demonstrating the excellent stability of this material. From the collector current dependence of the current gain, ideality factors of 1.3 and 1.2 for the emitter junctions have been obtained for devices on InP and GaAs, respectively.

Reference #491

Breakdown Behavior of GaAs/AlGaAs HBTs

by

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Abstract

Avalanche breakdown behavior at the collector junction of the GaAs/AlGaAs HBT has been studied. The dependence of collector-base breakdown voltage upon the collector doping concentration and thickness was investigated, showing expected functional behavior. Associated breakdown voltage calculations using simple punch-through considerations were found to be in close agreement with the maximum breakdown voltages - measured from devices displaying the most uniform junction breakdown.

Junction breakdown characteristics including both localized microplasma effects as well as uniform microplasma-free behavior were observed. At avalanche breakdown in the GaAs *p-n* junction, we report the first known observation of light emission from the collector-base junction of a GaAs/AlGaAs HBT. Collector-emitter breakdown characteristics showing expected negative resistance breakdown were also investigated. Associated current gain measurements were performed in connection with the analysis of the collector-emitter/collector-base breakdown voltages.

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An $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ heterojunction bipolar transistor

on GaAs substrate by molecular beam epitaxy

by

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Abstract

The $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ heterojunction bipolar transistors were grown and fabricated on a GaAs substrate by molecular beam epitaxy. In order to suppress the propagation of threading dislocations to the surface, a ten period $AlAs/In_{0.52}Al_{0.48}As$ (20Å/20Å) strained layer superlattice was incorporated twice with intervening undoped $In_{0.52}Al_{0.48}As$ layers. The devices with an emitter area of 50 x 50 μm^2 exhibited a typical common emitter current gain of 50, with a maximum of 63, at a collector current density of 2×10^3 A/cm^2.

Reference #479

Collector Offset Voltage of Heterojunction Bipolar Transistors

Grown By Molecular Beam Epitaxy

by

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Abstract

The collector-emitter offset voltages of AlGaAs/GaAs and InAlAs/InGaAs heterojunction bipolar transistors grown by molecular beam epitaxy have been investigated. Both geometrical and electrical asymmetry between emitter and collector junctions in these mesa isolated transistors account for the offset voltages observed. Devices exhibited offset voltages in the range of 50 to 300 mV depending on the structures and geometrical parameters. Several electrical and geometrical factors affecting the offset voltage are discussed in detail.

EXTREMELY LOW RESISTANCE NON-ALLOYED OHMIC CONTACTS ON GaAs USING InAs/InGaAs AND InAs/GaAs STRAINED LAYER SUPERLATTICES

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Abstract

Employing a structure consisting of n^+ InAs/InGaAs and InAs/GaAs strained layer superlattices (SLS) grown by molecular beam epitaxy on GaAs films, non-alloyed contact resistances less than $8.5 \times 10^{-8} \Omega cm^2$ have been obtained. Self-consistent simulations show that these extremely small non-alloyed contact resistances are due to the suppression of the depletion depth in the GaAs channel and tunneling through the SLS layer. Similar structures on InGaAs channels have led to non-alloyed specific contact resistances of about $1.5 \times 10^{-8} \Omega cm^2$. These results represent the smallest figures reported for these important material systems.

Reference #450

A GaAs METAL SEMICONDUCTOR FIELD EFFECT TRANSISTOR WITH EXTREMELY LOW RESISTANCE NON-ALLOYED OHMIC CONTACTS USING AN InAs/GaAs SUPERLATTICE

by

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ABSTRACT

GaAs MESFETs with extremely low resistance non-alloyed ohmic contacts have been demonstrated. The contact structure consists of an n^+- InAs/GaAs strained layer superlattice (SLS) and an InAs cap layer. Contact resistances of 0.036 Ω-mm and specific contact resistivities of 4.9 x 10^{-8} Ω cm^2 have been measured. These results represent the smallest figures reported to date for FETs on any material system. Non-alloyed MESFETs with 1-μm gate lengths had transconductances of about 210 mS/mm.

Reference #499

Low resistance nonalloyed ohmic contacts on p-type GaAs using GaSb/GaAs strained-layer superlattices

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ABSTRACT

The formation of ohmic contacts is of considerable importance in semiconductor devices, particularly, for high power, low noise microwave transistors and laser diodes. To obtain high performance and good reliability, a low-resistance ohmic contact is necessary. Conventional ohmic contacts to GaAs involve alloying at high temperatures, which cause diffusion of contact metals into the semiconductor. As device dimensions shrink, nonalloyed ohmic contacts become an almost inevitable part of the fabrication process, avoiding the lateral and vertical diffusion associated with high temperature processing. Using a GaSb/GaAs strained-layer superlattice (SLS) and a GaSb cap layer, we have obtained p-type nonalloyed ohmic contacts with specific contact resistivities as low as 3.16×10^{-7} $\Omega\cdot cm^2$, which is, to our knowledge, the lowest value reported to date for nonalloyed contacts on p-type GaAs. The samples investigated in this study were grown on semi-insulating (100)GaAs substrates by molecular beam epitaxy (MBE). The structure consists of a 0.2 μm undoped GaAs buffer, a 0.1 μm Be-doped (5×10^{18} cm^{-3}) GaAs channel, ten periods of 10 Å/10 Å Be-doped (1×10^{19} cm^{-3}) GaSb/GaAs SLS, and finally a 50 Å Be-doped (1×10^{19} cm^{-3}) GaSb cap layer. Detailed discussion of growth conditions, sample preparation and resistance measurements will be presented. Thermal stability, contact metal selectivity and the results of TEM studies will also be discussed.

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Calculation of the I–V Characteristics of Direct Tunneling Diodes

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We present a calculation of the I–V characteristics of direct tunneling diodes with an undoped tunneling barrier. The effect of band–bending is included in the calculation by solving two coupled one–dimensional Poisson's equations. The transfer matrix method is used for the calculation of the transmission probability of the tunneling electron whose complex **k**–vector is obtained from a $\mathbf{k}\cdot\mathbf{p}$ band structure calculation. An energy dependent density of states effective mass which is also calculated from the $\mathbf{k}\cdot\mathbf{p}$ band structure is used. Predictions for an $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/\ In_{0.53}Ga_{0.47}As$ diode which is lattice matched to InP agree quantitatively with experiment. Results obtained from models based on the effective–mass approximation is approximately a factor of four smaller than that of the present model.

Reference #476

AlGaAs/GaAs MULTIPLE QUANTUM WELL REFLECTION MODULATORS GROWN ON Si SUBSTRATES.

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ABSTRACT

We report for the first time large excitonic absorption at room temperature in AlGaAs/GaAs Multiple Quantum Well structures grown on Si substrates in a p-i-n configuration, using photocurrent measurements. We demonstrate an optical reflection modulator which is based on the quantum-confined Stark Effect and exciton broadening with a reverse bias voltage applied across the p-i-n structure. A 7.7% change in the reflectivity of the device with 6V reverse bias voltage was observed. These results demonstrate clearly that optical device quality GaAs/AlGaAs is obtainable directly on Si substrates which has great implications with regard to the monolithic integration of optical III-V and electronical Si-technology.

Reference #437

InGaAs/GaAs multiple quantum well reflection modulators

by

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ABSTRACT

We demonstrate a p-i-n reflection modulator consisting of a 50 period strained layer $In_{0.15}Ga_{0.85}As$ / GaAs multiple quantum well and a 5 period AlAs/GaAs quarter wave stack dielectric mirror, grown on a GaAs substrate by Molecular Beam Epitaxy. We observed a relative change in the reflectivity of the modulator of 12 % with 4.5V reverse bias voltage and at 0.996 μm wavelength.

Reference #464

InGaAs/GaAs STRAINED LAYER MQW ELECTROABSORPTION OPTICAL MODULATOR AND SELF-ELECTROOPTIC EFFECT DEVICE

Abstract. We observed a clear excitonic absorption effect at room temperature in MBE-grown $In_xGa_{1-x}As/GaAs$ strained layer Multiple Quantum Well structures and fabricated optical p-i-n modulators on the same structures. A change of 27% in the transmission , corresponding to a change in the absorption coefficient of 2260 cm^{-1}, with 6 volt reverse bias voltage and at 9710 Å wavelength was measured. We also operated the modulator as a Self-Electrooptic Effect Device, resulting in a non-linear optical input-output characteristic.

Multiple Quantum Well (MQW) p-i-n modulators, based on the quantum confined Stark effect have been demonstrated extensively in the AlGaAs/GaAs material system [1,2]. The ternary material InGaAs is however becoming increasingly interesting for optical modulator and laser applications in integrated optics because it allows operation in the infrared region. High frequency MQW electroabsorption optical modulators have been reported in the InGaAs/InP material system, grown by MOCVD [3], and in the InGaAs/InAlAs material system grown by MBE [4]. In this letter we report an MBE-grown p-i-n electroabsorption light modulator in the strained layer InGaAs/GaAs[5] material system. We first describe the modulator structure and the device fabrication . Then we discuss the electroabsorption effect which is the basis for the modulator operation along with the device performance. Finally we describe the performance as a Self-Electrooptic Effect Device (SEED)[6].

Band Lineup in $GaAs_{1-x}Sb_x/GaAs$ Strained-Layer Multiple Quantum Wells Grown by Molecular Beam Epitaxy

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Abstract

$GaAs_{1-x}Sb_x/GaAs$ strained-layer multiple quantum wells (MQWs) have been grown by molecular beam epitaxy and characterized by room temperature photoreflectance (PR). The PR spectra denote that high quality layers can be grown in the $GaAs_{1-x}Sb_x/GaAs$ system. The method for determining the band offset Q_{vh} is discussed in this strained-layer system. Based on this treatment and the band gap formula of bulk $GaAs_{1-x}Sb_x$ a value of the heavy hole band offset, $Q_{vh} \sim 1.7$ has been obtained for $GaAs_{1-x}Sb_x/GaAs$ with $x = 0.1$ establishing a type II structure with electrons in GaAs layers and heavy and light holes in $GaAs_{1-x}Sb_x$ layers, respectively.

Reference #433

PACS numbers 78.65 -S 78.65 Fa.

Optical Transitions Involving Unconfined Energy States

in InGaAs/GaAs Multiple Quantum Wells

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Optical transitions with energies higher than that of GaAs bandgap in highly strained $In_xGa_{1-x}As/GaAs$ multiple quantum well structures have been observed in photoreflectance spectra. In some samples as many as seven such structures were present. We identify them as transitions between the unconfined electron states and the confined heavy hole states. For energies below GaAs signal, intense transitions corresponding to such unconfined subbands were also observed. The intensity of the transitions involving unconfind subbands decreases with increasing well width, but is weakly dependent of the mole fraction, x. The transmission coefficients are calculated in order to locate the positions of the unconfined subband energies. Good agreement is obtained between the experimental data and the theoretical calculation.

PACS numbers 78.65-5, 78.65-Fa

Reference #430

Photoreflectance, Absorption and Nuclear Resonance Reaction Studies of $Al_xGa_{1-x}As$ Grown by Molecular Beam Epitaxy

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Abstract

The photoreflectance (PR) spectra of bulk $Al_xGa_{1-x}As$ alloys with $x \leqslant 0.45$ were studied. The observed lineshapes from different samples suggest that PR technique is very sensitive to the material quality, surface condition and the background impurities. The energy gap derived from the PR spectra compared well to that obtained from the absorption spectra. The relationship between the energy gap and the Al mole fraction value, x, was established through the nuclear resonance reaction analysis (NRRA). The electric field near the surface was calculated from the periodicity of Franz-Keldysh oscillations observed in many of the samples. From our analysis, we believe that the number of oscillations shown in PR spectra corresponds to sample quality, in general. We also believe that the low-field-like lineshape is mainly caused by the fluctuation of Al distribution along the growth direction. An additional feature related to the impurity transition was also observed in the spectra.

Reference #

PACS No. 78.20.WC

Excitonic absorption in modulation-doped $GaAs/Al_xGa_{1-x}As$ quantum wells

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We have performed transmission measurements in a range of undoped through heavily modulation doped $GaAs/Al_xGa_{1-x}As$ multiple-quantum-well structures (MQW). The observed absorption spectra demonstrate quenching of the excitonic oscillations with increasing quasi-two-dimensional electron gas. The electron density corresponding to the total bleaching of the lowest excitonic oscillation is greater than or equal to 3×10^{11} cm^{-2} for a quantum well size of 200 Å. Theoretical calculations of the absorption spectra which include the effect of carrier screening have been made. The results show that both long-range and short range many-body effects should be included to explain the experimentally observed spectra. In the modualtion doped case, we conclude that the phase-space filling and exchange of the electron gas are the dominant effects on excitonic absorption. From the observation that the linewidth increases with the electron density, we demonstrate that the exciton lifetime reduces due to the interaction between the electrons and the excitons.

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pacs # 71.35.+Z, 78.65.Fa

Reference #405

Band Structure Determination of Modulation Doped Multiquantum Well Heterostructures

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Abstract

We present a precise and effective numerical procedure to model the band diagram of modulation doped multiquantum well heterostructures. This method is based on a self-consistent iterative solution of the Schrödinger equation and the Poisson equation. It can be used rather easily in any arbitrary modulation-doped structure. In addition to confined energy subbands, the unconfined states can be calculated as well. Examples on realistic device structures are given to demonstrate capabilities of this procedure. The numerical results are in good agreement with experiments. With the aid of this method we have identified the transitions involving both the confined and unconfined conduction subbands in a modulation doped AlGaAs/GaAs superlattice, and in a strained layer InGaAs/GaAs superlattice. These results represent the first observation of unconfined transitions in modulation doped multiquantum well structures.

Reference #440

PACS numbers 73·20·DX 78·65·Fa

PHOTOLUMINESCENCE STUDIES OF GaAs GROWN ON InP SUBSTRATES BY MOLECULAR BEAM EPITAXY

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Abstract

GaAs based field effect transistor structures have been grown on InP substrates with the InGaAs/GaAs strained layer superlattices and 1.5 μm GaAs layer as the buffer. The low temperature (4K) photoluminescence (PL) from this GaAs buffer has been studied for the first time. Among five observable peaks, the excitonic transition at energy 1.513 eV and the impurity associated recombination at energy 1.483 eV have been identified with the aid of reflection, absorption, and temperature and excitation-intensity dependent PL measurements. The peak at 1.504 eV, most probably due to an exciton bound to a defect, is greatly enhanced compared with that of homoepitaxially grown GaAs. The optical results show that GaAs films of good quality can be grown on InP substrate, which is consistent with device results.

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